Source Detection in 2D High Noise Emission Type Problems Using Cone Data

Weston Baines and Peter Kuchment   Texas A&M Dept. of Mathematics

Abstract

The development of methods for source detection in high noise environments is an important topic in single-photon emission computed tomography (SPECT) medical imaging and homeland security applications. The detection of low emission nuclear sources in the presence of significant background noise ($SNR \leq 0.01$) is of great interest since such a robust detection system can prevent the smuggling of weapons-grade nuclear material. A source detection method based on the analysis of data obtained from Compton type cameras and their analogs using deep learning is developed and evaluated, and compared to previous statistical detection techniques.

Compton type cameras

The Compton camera is a new type of γ-particle detector that provides a surface cone of possible incoming directions of a detected photon. In the absence of mechanical collimation, signal strength is effectively maintained, although data analysis becomes more complex.
Neutron detectors (albeit based upon a different physics rather than Compton scattering) that provide similar cone information are currently being developed. Since the arising problems are mathematically equivalent, we will not specify the type of particles detected.

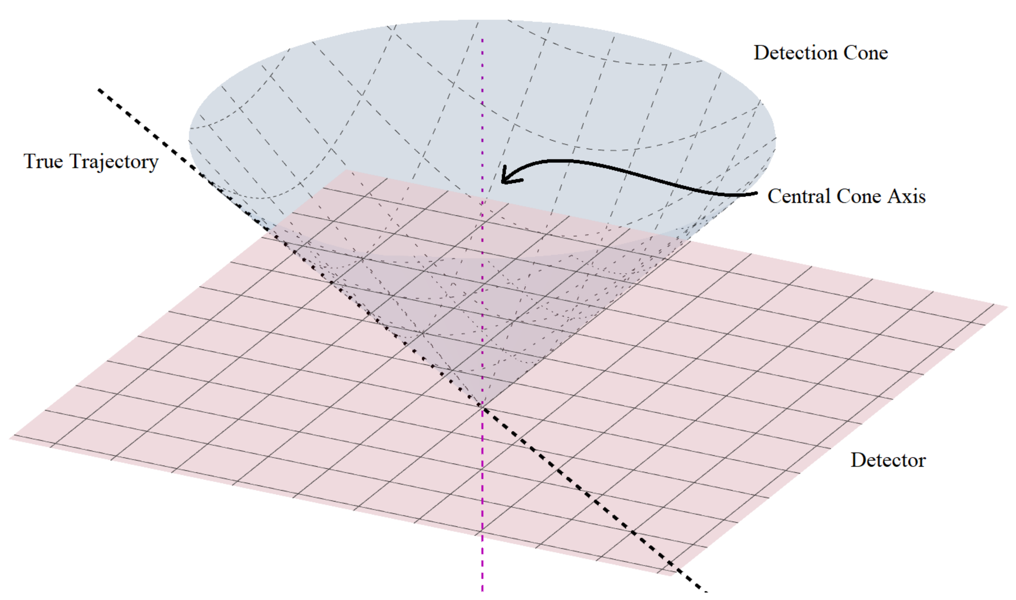

Figure 1: Surface cone produced by Compton camera from particle detection

Contact Information

Email kuchment@math.tamu.edu
Email bainesw1@math.tamu.edu

Introduction

In order to detect emission sources, ideally one would try to reconstruct from the signal the source distribution function. When the data (e.g., in SPECT) is sufficiently well behaved, analytic reconstruction is possible using Compton cameras [3]. However, when the signal of interest is embedded in a high noise environment, such as in the case of illicit nuclear source detection, analytic reconstruction is impossible, although in this case one is mostly interested in the presence of a source, rather than its exact location.
In order to have any hope of detecting the small fluctuations in background noise produced by the presence of a small signal, direction sensitive detectors are necessary. The following options for obtaining directional sensitivity are available:

Mechanical collimation - only rays incident along a certain line are allowed to reach the detector. This effectively significantly reduces the signal strength and thus becomes unsuitable for low signal to noise ratios.

Compton type cameras - Novel type of gamma and neutron detectors that determine a surface cone of possible incident trajectories, rather than their exact directions.

Backprojection Techniques

Previously Compton camera data was processed using backprojection techniques, wherein lines are drawn over all possible incident trajectories observed, and a source is determined to be present if a statistically significant concentration of intersections occurs in a localized area. This method has proven successful for very low SNR levels in the presence of certain number of ballistic particles from the source reaching the detector and a sufficiently high number of observations (which corresponds to a sufficiently long observation time) [1].

Acknowledgements

We would like to acknowledge the following organizations for their support of this research:
National Science Foundation (NSF)
Texas A&M Cyclotron Institute

Neural Networks

Deep learning is investigated as a path to source detection with a shorter observation time and without prior mathematical processing such as backprojection. A two stage process is adopted for this task detailed in the flow chart (Fig. 2 right).

- Detector data is taken as input. The output is "yes" if a source is detected and "no" otherwise.
- Convolutional Denoising Autoencoder (CDAE) suppresses the background noise in the signal; trained by inputting noisy data and targeting denoised data.
- Convolutional Neural Network (CNN) Classifier determines if output of CDAE indicates presence of a source; trained by inputting detector data processed by the CDAE for which it is known whether the source is present.

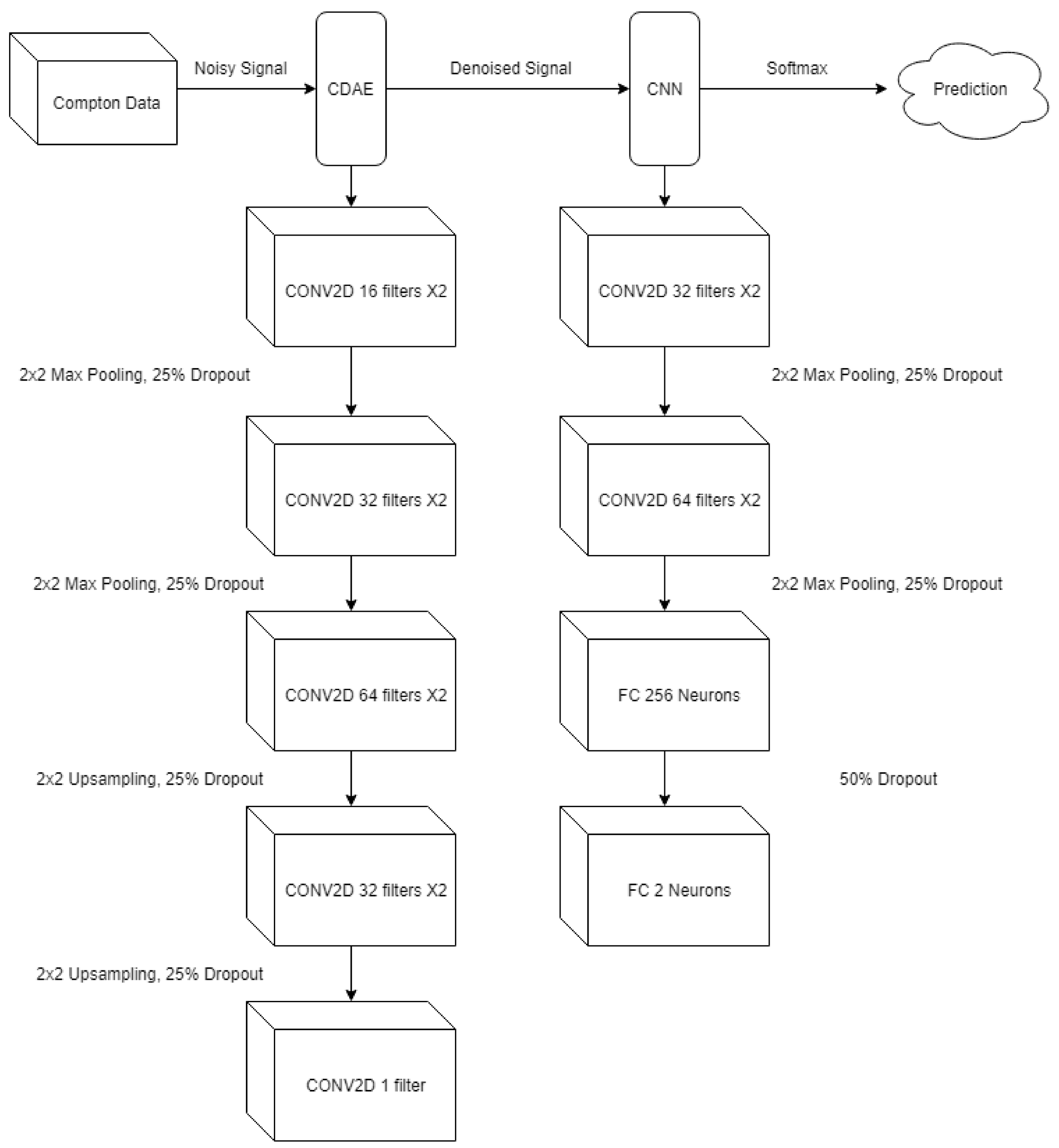

Figure 2: Overview of neural network architecture

Results

Bkgnd Cnt	Sensitivity	Specificity
10000	.960/.909	.998/.644
5000	.949/.725	.882/.528
2000	.732/.530	.519/.510

Table 1: Neural Network Performance SNR 2% / 1%

Bkgnd Cnt	Sensitivity	Specificity
10000	.06/.00	1.0/1.0
5000	.06/.00	1.0/1.0
2000	.02/.02	1.0/1.0

Table 2: Back Projection Performance SNR 2% / 1%

Future Research

- Optimize the architecture for shorter observation time and lower SNR.
- Move to 3D case.
- Test neural network approach to Compton γ camera data, when domain contains complex attenuating and scattering cargo configuration (i.e. ballistic particles might not be present, thus rendering the backprojection algorithm useless) [2].
- Test the neural network approach on real data.

References

[1] M. Allmaras, D. Darrow, Y. Hristova, G. Kanschat, P. Kuchment, Detecting small low emission radiating sources, *Inverse Problems & Imaging*, **7** (1) (2013), 47–79.

[2] M. Allmaras, A. Ciabatti, Y. Hristova, P. Kuchment, A. Olson, J. Ragusa, Passive Detection of Small Low-Emission Sources: Two-Dimensional Numerical Case Studies, *Nuclear Sci. and Eng.* **184** (2016), no.1.

[3] F. Terzioglu, P. Kuchment, and L. Kunyansky, Compton camera imaging and the cone transform : A brief overview, *Inverse Problems*, **34** (2018), No. 5, 054002.